

# RIE-Texturing of Multicrystalline Silicon Solar Cells

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## ABSTRACT

We developed a maskless plasma texturing technique for multicrystalline silicon (mc-Si) cells using Reactive Ion Etching (RIE) that results in higher cell performance than that of standard untextured cells. Elimination of plasma damage has been achieved while keeping front reflectance to extremely low levels. Internal quantum efficiencies as high as those on planar cells have been obtained, boosting cell currents and efficiencies by up to 7% on evaporated metal and 4% on screen-printed cells.

## 1. Introduction

Mc-Si cell performance is close to that of single c-Si cells, with the major difference resulting from the inability to texture mc-Si affordably. This has reduced the cost-per-watt advantage of mc-Si. A low-cost, large-area, maskless texturing technique is expected to significantly impact the cost and performance of mc-Si photovoltaic technology.

Inomata et al. reported the development of a Reactive Ion Etching (RIE) texturing process using Cl<sub>2</sub> gas, which textures multiple wafers per batch, making it attractive for mass-production [1]. Using this process, they produced a 17.1% efficient 225-cm<sup>2</sup> mc-Si cell, which is the highest efficiency mc-Si cell of its size ever reported. This shows that RIE texturing can be done without causing performance-limiting damage to Si cells. We will discuss an RIE-texturing process that avoids the use of toxic and corrosive Cl<sub>2</sub> gas.

## 2. Experimental Procedure

We developed several metal-catalyst assisted RIE-texturing techniques using SF<sub>6</sub>/O<sub>2</sub> plasma chemistry in a Plasma-Therm 790 reactor [2]. The textured surfaces exhibit reflectance as low as 1 to 5 % for wavelengths below 1  $\mu$ m without the benefit of anti-reflection films. We investigated several texturing processes in conjunction with various damage-removal etches (DRE) to determine which produced the highest cell performance for both screen-printed and evaporated metal cell fabrication sequences.

The emitter diffusion was performed by using the dopant oxide solid source (DOSS) process. Source wafers with spin-on dopant applied to both sides were introduced to the furnace together with the samples so that every sample is

stacked in front of a source wafer on one side only. This diffusion technique was used to take advantage of the in-situ oxide grown in the same furnace cycle as the phosphorus diffusion. This one step furnace process leads to phosphorus diffusion, textured, in-situ oxide passivated solar cells that are immediately ready for metallization. Finally, the cells received a single-layer plasma-enhanced chemical vapor deposited (PECVD) silicon-nitride antireflection coating (ARC).

## 3. Results

We compared four different metal-assisted texture processes: Al-assisted, Cr-assisted, Ti-assisted, and a chamber-conditioned texture. These were used in conjunction with a dilute acid DRE, a KOH DRE, or no DRE at all. Tables 1 and 2 show the wafer average efficiencies of evaporated-metal and screen-printed cells, respectively.

Table 1. Wafer average efficiency of up to 9 **metal-evaporated** cells, each 4-cm<sup>2</sup>, measured at Georgia Tech. The average of the planar control cells was **13.3%**. The cells in bold exceeded the efficiency of the controls.

	Acid DRE	No DRE	KOH DRE
Ti-assisted	<b>14.1</b>	<b>14.2</b>	
Conditioned	<b>14.0</b>	<b>13.7</b>	12.9
Al-assisted	<b>13.6</b>	12.8	
Cr-assisted	<b>13.8</b>	<b>13.9</b>	

Table 2. Wafer average efficiency of up to 9 **screen-printed** cells, each 4-cm<sup>2</sup>, measured at Georgia Tech. The average of these planar control cells was **13.4%**. The cells in bold exceeded the efficiency of the controls.

	Acid DRE	No DRE	KOH DRE
Ti-assisted	<b>13.8</b>	13.2	
Conditioned	<b>14.0</b>	12.8	13.4
Al-assisted	<b>13.6</b>	13.0	
Cr-assisted	<b>13.8</b>	12.7	

For cells that performed better than the controls, most of the improvement was due to increased short-circuit current, with slight additional increases in open-circuit voltage. To investigate this further, we measured the internal quantum efficiency (IQE) and spectral reflectance of median cells from

representative groups. Measurements of the Ti-assisted, metal-evaporated cells are shown in Figure 1.

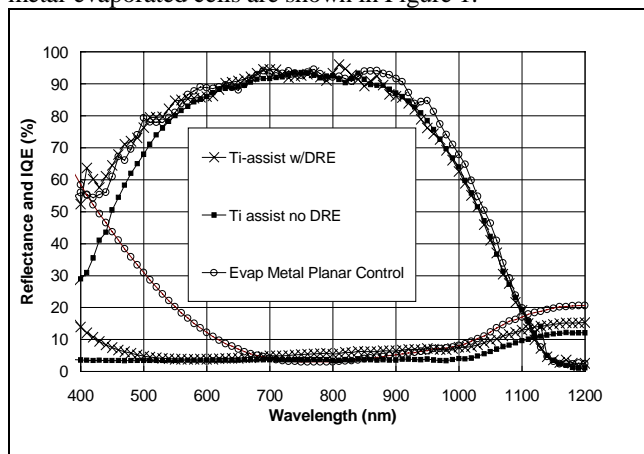


Figure 1. IQE and hemispherical reflectance of three metal-evaporated mc-Si cells. The Ti-assisted cell without DRE has the lowest reflectance, but suffers from a poor blue-response. The Ti cell with acid DRE has only slightly higher reflectance, but its IQE is as high as that of the planar control cell.

For the screen-printed cells, the process that produced the best results was the conditioned texture process. IQE and reflectance curves of these cells are shown in Figure 2.

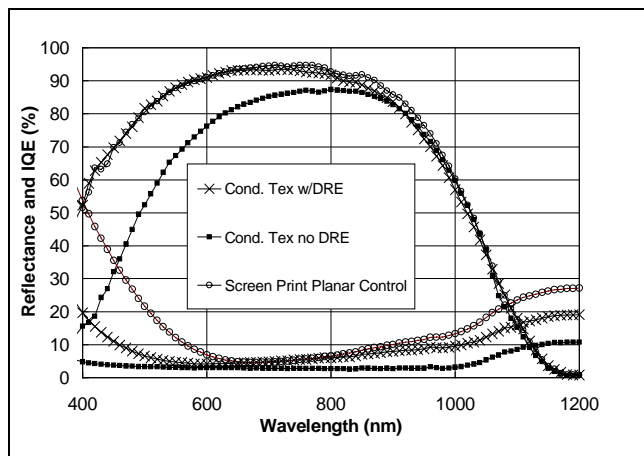


Figure 2. IQE and hemispherical reflectance for three screen-printed mc-Si cells. Again, the textured cell without DRE has the lowest reflectance, but even poorer blue response. The IQE of a textured cell is completely restored to that of the planar cell by the DRE with only a slight increase in reflectance.

#### 4. Discussion

The RIE-texture process produces extremely low-reflectance surfaces. The solar weighted reflectance of the no-DRE cells in Figs. 1 and 2 are 3.6% and 3.4%, respectively, including the reflectance from the gridlines. However, the RIE process causes some shallow surface damage. This results in the recombination of carriers generated by short-

wavelength light absorbed near the surface, resulting in low blue-response.

The DRE, consisting of a 10 second dip in a nitric/HF acid mixture, removes the entire damaged region, as indicated by the complete recovery of the IQE to that of the untextured cells. Yet, because so little of the texture is removed, as shown in Fig. 3, the solar-weighted reflectance increases to only 5.9% and 7.0% for Ti and conditioned textures, respectively. This compares to 13.0% and 12.8% for metal-evaporated and screen-printed planar cells with a single-layer ARC.

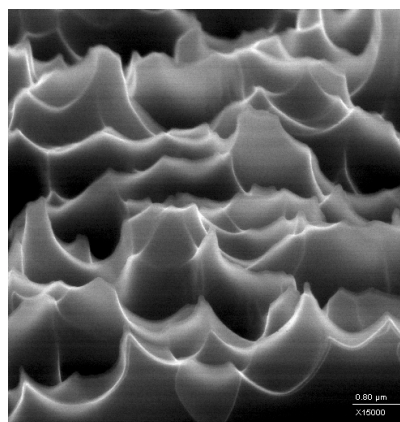


Figure 3. SEM of conditioned-texture cell after acid DRE.

Because the IQE of the Ti-textured cell without DRE is not too low, the metal-evaporated cells with no DRE still outperform the planar controls, and offer some promise that simplified processing without DRE may be possible. Perhaps this is due to the slight surface etching that takes place when oxide is removed just before metal gridline evaporation.

The conditioned RIE process with an acid DRE seemed to offer the largest and most consistent improvements, especially in the important case of screen-printed cells, which will be the most likely use of textured mc-Si. The conditioned texture process will be evaluated further for process simplification, such as shortening of the RCA-clean that precedes the DRE.

#### 5. Conclusions

This investigation determined that RIE-texturization of mc-Si followed by a short wet-chemical etch can increase the performance above that of planar cells by up to 7% for metal-evaporated and 4% for screen-printed cells, respectively. Typical commercial planar mc-Si cells with a single-layer ARC should be able to use this process to boost their performance.

#### 6. Acknowledgements

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#### REFERENCES

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